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FINAL REPORT

March 1, 1964 - January 31, 1970

to

ADVANCED RESEARCH PROJECTS AGENCY

ARPA ORDER NO.	125
CONTRACT NO.	NONR 285(60)
TITLE	ELECTRON SCATTERING

Benjamin Bederson, Project Director
Research Division
School of Engineering and Science
Physics Department
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University Heights
New York, N.Y. 10453

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SUMMARY

The work performed under Contract No. NONR 235(60) is summarized. It was funded by the Advanced Research Projects Agency from 1 March 1964 to 31 January 1970, and was directed by Professors Benjamin Bederson, Larry Spruch and Sidney Borowitz. The principal subjects of investigation were experimental and theoretical aspects of atomic collisions and atomic structure. Lists of contributed papers, invited talks, lectures and colloquia, published papers and other related activities, and of students who have received their Ph.D. degrees under ARPA support are given.

1. INTRODUCTION

This Final Report summarizes the work performed under Contract No. NONR 235(60) funded by the Advanced Research Projects Agency, from 1 March 1964 to 31 January 1970. The work was performed primarily in the Atomic Beams and Plasma Physics Laboratory at the University Heights campus of New York University, under the direction of Professor Benjamin Bederson. For a short period (1966-67), theoretical work directed by Professors L. Spruch and S. Borowitz were also supported by this contract.

The main thrust of this work was concerned with the study of the interactions of electrons with simple atomic systems at low

energies, and with the study of the interaction of simple atoms and molecules with strong electric fields. The N.Y.U. group was among the first to undertake such studies, after World War II, starting with support from the Office of Naval Research in 1952. N.Y.U. has been among the leading developers and users of crossed-beam techniques since that time.

Among the important contributions of the experimental group have been the performance of the first energy- and angle-dependent cross section measurements in atomic physics using spin selection and analysis, the development of the atomic beam recoil technique to study differential and total elastic and inelastic cross sections for the scattering of electrons by atoms and molecules, the first direct measurement of a cross section for the scattering of electrons by excited (metastable) atoms other than for ionization; the first excitation cross section performed with spin analysis, the first measurement of a polarizability anisotropy in an atomic beam, and the first measurement of an electric dipole polarizability using a balance technique.

Professor Spruch and his students have pioneered many new developments in atomic collision theory, among these being the use of minimum principles to obtain bounds on scattering cross sections, the extension of effective-range scattering theory (very useful at low electron energies) to atomic collisions, and a continuing activity in the general area of long-range forces and in the role played by these in atomic collision processes.

The output of these groups is summarized in the following sections:

2. Contributed Talks.
3. Invited Talks, Lectures and Colloquia.
4. Published Papers.
5. Other project-related activities of Principal Investigators.
6. List of students who have received Ph.D. degrees with ARPA support.

2. CONTRIBUTED TALKS

"Near Threshold Electron Excitation of $4^2P_{1/2,3/2}$ Potassium Using Atomic Beam Recoil", K. Rubin and B. Bederson, Bull. Am. Phys. Soc. II, 10, 49, (1965).

"Low Energy Electron Scattering by Atomic Oxygen", G. Sunshine, B.B. Aubrey and B. Bederson

"Electron-Potassium Excitation Studies Using Atomic Beam Recoil"
K. Rubin and B. Bederson.

"Influence of Hyperfine Structure on Electron-Alkali Atom Spin Exchange Collisions", K. Rubin.

Above three papers presented at IVth International Conference on Physics of Electronic and Atomic Collisions, Quebec, June 1965.

"Electric Polarizabilities of Metastable Mercury", J. Levine, R. Celotta, and B. Bederson, Washington APS, April 1966.

"Observation of Change of Spin-Orientation of Potassium Atoms in Inelastic Scattering by Low-Energy Electrons as a Function of Scattering-Angle", K. Rubin, B. Bederson, R. Collins and M. Goldstein, Vth ICPEAC, Leningrad USSR, July 1967.

"Change of Spin Orientation of Potassium Inelastically Scattered by Low-Energy Electrons", M. Goldstein, R. Collins, K. Rubin and B. Bederson, Bull. Am. Phys. Soc. 12, 1044 (1967).

"Elastic Differential Exchange Cross Section Measurements for Scattering of Low-Energy Electrons by Potassium", R.E. Collins, M. Goldstein, K. Rubin and B. Bederson, Bull. Am. Phys. Soc. 12, 1044 (1967).

"Measurement of the Total Cross Section for the Scattering of Slow Electrons by Metastable Argon", R. Celotta, H.H. Brown and B. Bederson.

"Beam Measurement of Spin-Flip Cross Sections for $4^2S_{1/2} - 4^2P_{1/2,3/2}$ Excitation of Potassium by Electrons", M. Goldstein, K. Rubin, R.E. Collins and B. Bederson.

"Differential and Differential Exchange Cross Sections for Elastic Electron-Potassium Collisions", R.E. Collins, B. Bederson, M. Goldstein and K. Rubin.

Above three papers presented at First International Conference on Atomic Physics, N.Y.U., June 1963.

"Spin-State Analysis in Inelastic Electron-Atom Collisions", K.Rubin,
B.Bederson, M. Goldstein and R.E.Collins.

"Summary of Recent Spin-Analyzed Electron-Potassium Differential
Cross Section Measurements", B.Bederson, R.E.Collins,
M. Goldstein and K. Rubin.

Above two papers presented at the International Symposium on Physics of One-
and Two-Electron Atoms, Munich, Germany 1968.

"Total Cross Sections for Electron-Potassium Scattering", R.E.Collins ...
21st GEC, Boulder, Colorado 1968.

"Differential and Differential Exchange Elastic Cross Sections
. for Scattering of Low-Energy Electrons by Potassium",
R.E.Collins, B.Bederson, M.Goldstein and K. Rubin.

"Scattering of Low-Energy Electrons by Metastable Argon",
R.Celotta, H.H. Brown and B.Bederson.

Above two papers submitted to VIth ICPEAC, Cambridge, Mass. 1969.

"Elastic Scattering of Atomic Hydrogen by Slow Electrons", P.N.Eisner,
B.B. Aubrey, T.M.Miller and B.Bederson, N.Y. APS, January 1969.

"Relative Cross Section for Electron Scattering by Atomic Nitrogen (0.2-3eV)",
T.M.Miller, B.B.Aubrey, P.N.Eisner and B.Bederson, 22 GEC Gatlinburg, Tenn.,
Oct. 29, 1969.

3. INVITED TALKS, LECTURES AND COLLOQUIA ON THE ARPA RELATED WORK

Presented at:

University of Connecticut	1964-5	B. Bederson
Yale University Howard University	1965-6	B. Bederson
C.C.N.Y. Lehigh University United Aircraft Corp., E.Hartford	1966-7	B. Bederson
Massachusetts Inst. of Tech.	1967	L. Spruch
University of Connecticut Georgia Institute of Technology University of Massachusetts Columbia University Renssalaer Polytechnic Inst.	1969-70	B. Bederson

"Scattering of an Electron Beam by Polarized Atoms", Invited paper presented by B.Bederson at Annual Meeting of APS, Chicago, 1968.

"Atom Beam Scattering Studies", presented at Review of Gaseous Interactions,
U.S.Army Research Office-Durham, Aberdeen Proving Ground, Md., May 6, 1969.

"Review of Polarized Atom Experiments at N.Y.U.", presented at Polarized Electron and Atom Workshop, J.I.L.A., University of Colorado, Aug. 7-9, 1969.

4. PUBLISHED PAPERS

"Electrical Water Flow Monitor", J. Levine, Rev. Sci. Inst. 36, 105 (1965)

"Projection Operators in the Unified Reaction Theory", Y. Hahn, Phys. Rev., 142, 603 (1966).

"Relativistic versus Nonrelativistic Scattering of Slow Electrons", L. Spruch, Phys. Rev. Lett. 16, 1137 (1966).

"Collective Oscillations of Atoms in the Hartree-Fock Approximation", S. Wieder and S. Dorowitz, Phys. Rev. Lett. 16, 724 (1966).

Beam Measurements of Atomic Polarizabilities, B. Bederson and E. Robinson in Molecular Beams, Advances in Chemical Physics, Vol. X, edited by J. Ross (Interscience, N.Y. 1966) pp 1-27.

"Metastable 3P_2 Rare Gas Polarizabilities", E.J. Robinson, J. Levine and B. Bederson, Phys. Rev. 146, 95 (1966).

"Remarks on Variational Bounds in Scattering Theory", Y. Hahn and L. Spruch, Phys. Rev. 153, 1159 (1967).

"Variational Lower Bounds on Electron-Hydrogen s-wave Phase Shifts", Y. Hahn, P. Henry, C. Kleinman and L. Spruch, Phys. Rev. 153, 73 (1967).

"Static Green's Function for Elastic e-H Scattering and Resonance", I. Aronson, Y. Hahn, P. Henry, C. Kleinman and L. Spruch, Phys. Rev. 159, (1967).

"Elastic Differential Spin Exchange Cross Sections for Scattering of Slow Electrons by Potassium", K.E. Collins, M. Goldstein, K. Rubin and B. Bederson, Phys. Rev. Lett. 19, 1366 (1967).

'Crossed Electron-Neutral Beams; B. Bederson, in Methods of Experimental Physics, Vol. 7A, B. Bederson and V.L. Fite, Eds., Academic Press 1968.

"Measurement of the Electric Dipole Polarizabilities of Metastable Mercury", J. Levine, L. Celotta and B. Bederson, Phys. Rev. 171, 31 (1968).

"Potassium Electron Elastic Spin-Exchange: Comparison of Experiment with a Close-coupling Calculation", R.E. Collins, M. Goldstein, K. Rubin and B. Bederson, Phys. Letters 27A, 440 (1968).

"Electron-Alkali Metal Inelastic Recoil Experiments with Spin Analysis: Experimental Method and the Small-Angle Behavior of the $4^2S_{1/2}$ - $4^2P_{1/2,3/2}$ Excitation of Potassium, K. Rubin, E. Bederson, M. Goldstein and R.E. Collins, Phys. Rev. 182, 201 (1969).

"An Electron Gun for Atomic Beam Recoil Scattering Experiments", R.E. Collins, B.B. Aubrey, P.N. Eisner and R.J. Celotta, Rev. Sci. Inst., In Press (1970).

6. PH.D. STUDENTS

CURRENT POSITION (1970)

Jacob M. Hammer,	1957	Solid State Division, David Sarnoff Research Center, R.C.A., Princeton, N.J.
Herbert Malamud,	1958	Director of Research, Radiation Research, Inc., Westbury, N.Y.
Kenneth Rubin,	1959	Assoc. Professor of Physics, C.U.N.Y., N.Y.
Arthur Salop,	1961	Research Scientist, Research Lab. Lockheed M and S, Palo Alto, Cal.
Julius Perel,	1961	Section Chief, Electro-Optical Systems, Inc., Pasadena, Cal.
Edward Pollack,	1963	Assoc. Professor of Physics, University of Connecticut, Storrs, Conn.
Kotusingh Lulla,	1963	Professor of Physics, N.Y. Institute of Technology, Old Westbury, N.Y.
William Aberth,	1963	Research Scientist, Stanford Research Institute, Palo, Alto, Cal.
Edward J. Robinson,	1964	Assoc. Professor of Physics, N.Y.U.
Peter Dittner,	1965	Oak Ridge National Laboratories, Oak Ridge, Tenn.
Gabriel Sunshine,	1965	Chairman and Prof. of Physics Dept., N.Y. Inst. of Tech., Old Westbury, N.Y.
Judah Levine,	1966	Research Scientist, National Bureau of Standards, Boulder, Colorado
Edward Gray,	1966	Aerospace Corp., El Segundo, Cal.
Philip Eisner,	1968	Research Scientist, G.C. Dewey Corp., N.Y.
Richard Collins,	1968	Research Scientist, Amalgamated Wireless, Ltd., Adelaide, Australia

Robert Celotta,	1969	Postdoctoral Fellow, J.I.L.A., Univ. of Colorado, Boulder, Colo.
Marvin Goldstein,	1969	Research Scientist, Bell Telephone Labs., Whippany, N.J.
Henry Schwartz,	1970	Postdoctoral Scientist 1970-71 Catholic University, Nijmegen, Netherlands

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ABSTRACT

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